Magma ascent and eruption forecasting at Deception Island Volcano (Antarctica) evidenced by δD and δ[18]O variations

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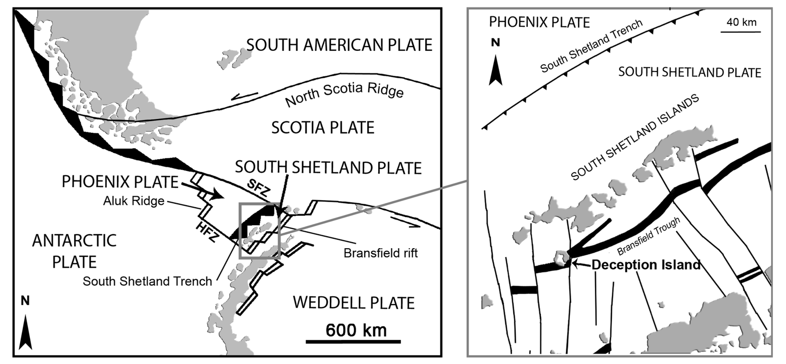
Introduction

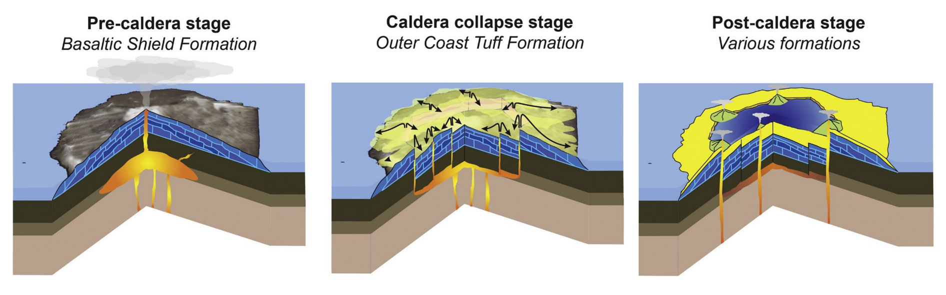
Geochemistry of volatiles in active volcanoes provides insights into the magmatic processes and evolution at depth, such as magma evolution and degassing, which can be implemented into volcanic hazards assessment.

Deception Island (Antarctica)



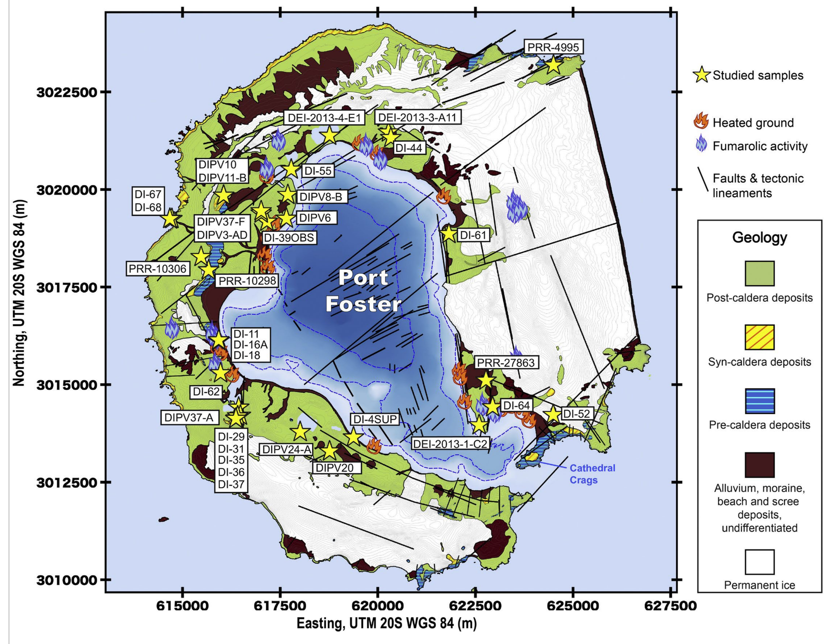
The Island is located at the southwestern end of Bransfield Strait, 100 km north of the Antarctic Peninsula.(Modified from Geyer et al. 2019)

Hydrogen and oxygen isotopic variations in the volatiles trapped in the Deception Island rocks provide essential information on the processes controlling the magmatic evolution and eruption dynamics in this volcanic suite.



The construction of the Island is separated into three evolutionary stages pre-, syn- and post-caldera. Source: Geyer et al. (2019)

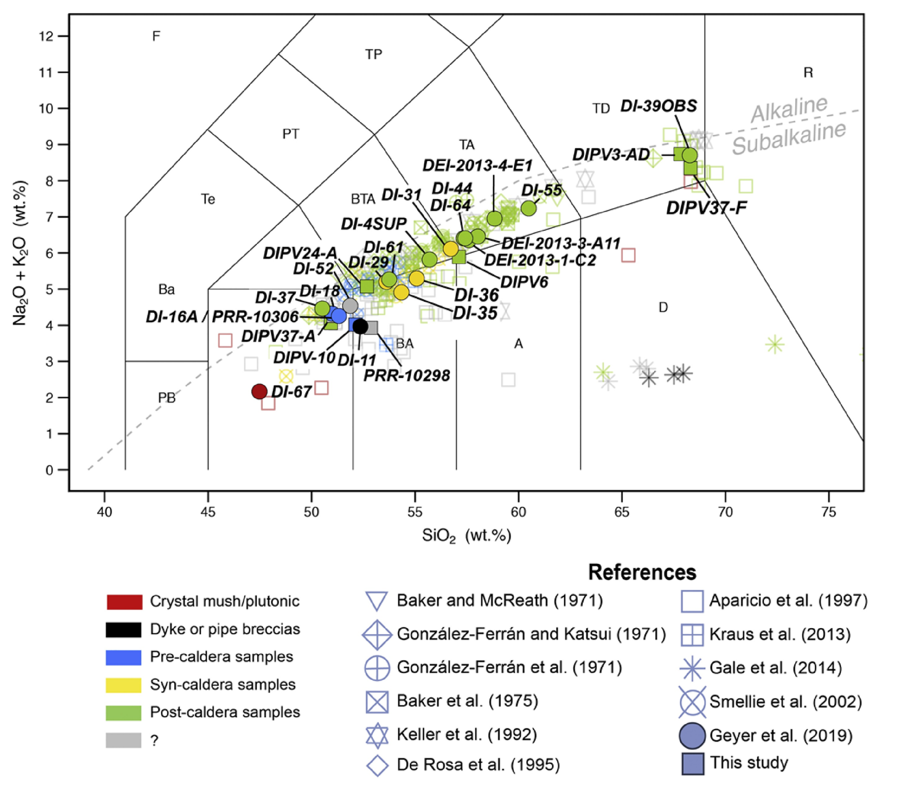
Deception Island is one of the most active volcanoes in Antarctica, with more than 20 explosive eruptive events registered over the past two centuries.



Simplified geological map of Deception Island showing the location of the analyzed samples, and distribution of the two main tectonic fault sets (NW-SE and NE-SW). (Modified from Alvarez-Valero et al. 2020).

Volcanic and magmatic evolution has been strongly marked by the development of a collapse caldera occurred around 4000 years ago.

Volcanic rocks are tholeiitic, from basalts to trachydacites and rhyolites, and follow an alkalinity-increasing trend at the upper end of the subalkaline field in the Total Alkali vs. Silica diagram

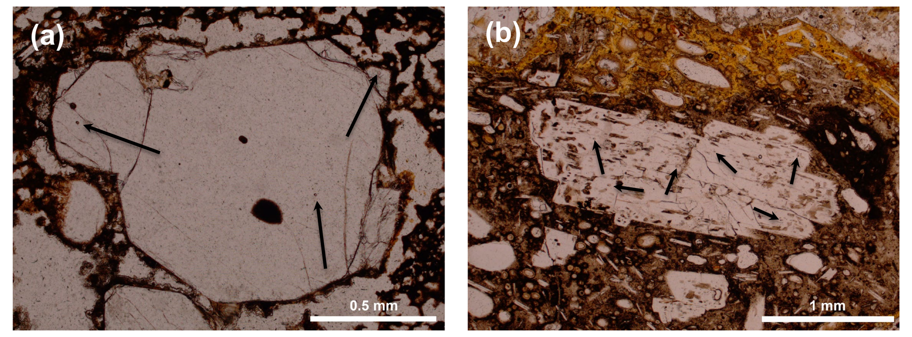


Total Alkali vs. Silica diagram (Le Bas et al., 1986) for the DI samples. Source: Alvarez-Valero et al. (2020)

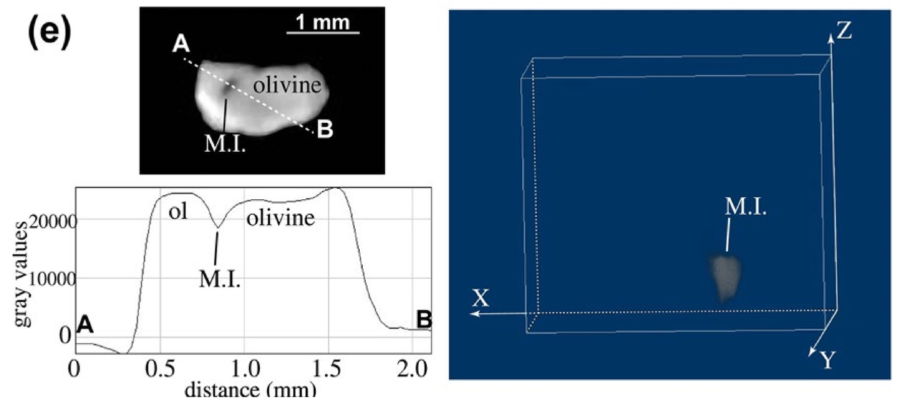
Results

δD, δ[18]O and H_2O(%) contents were analysed in glass and melt inclusions of pre-, syn- and post-caldera samples.

Glass and melt inclusions

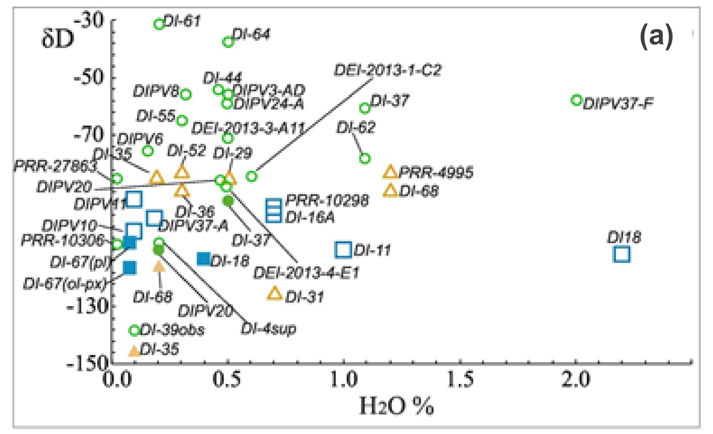


Examples of melt inclusions (arrows)-bearing phenocrysts (a) syn-caldera olivine and (b) pre-caldera plagioclase immersed in a sideromelane + palagonitic glassy matrix. (Modified from Alvarez-Valero et al., 2020).

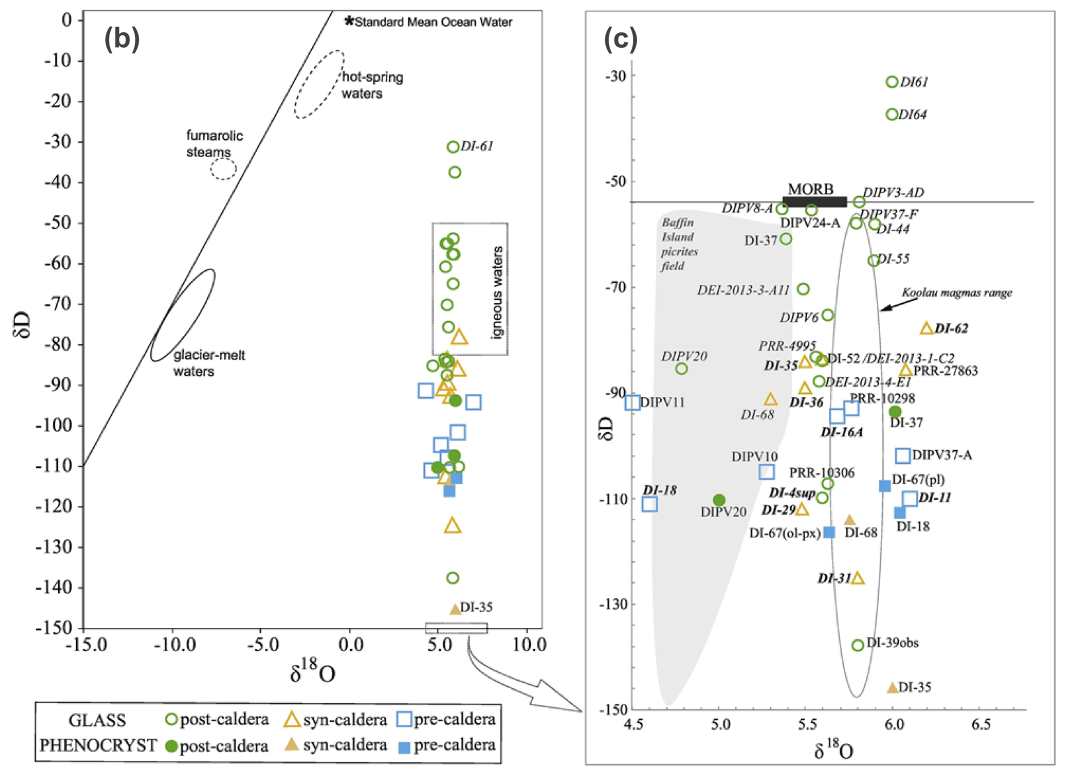


Size estimation and shape (3D) reconstruction of a melt inclusion within an olivine crystal obtained by micro-computed tomography (micro-CT). (Modified from Alvarez-Valero et al. 2020).

δD, δ[18]O and H_2O (%) contents



Isotopic compositions change geographically depending on the proximity to different external water sources. There is also a correlation between isotopes and fault systems in the island

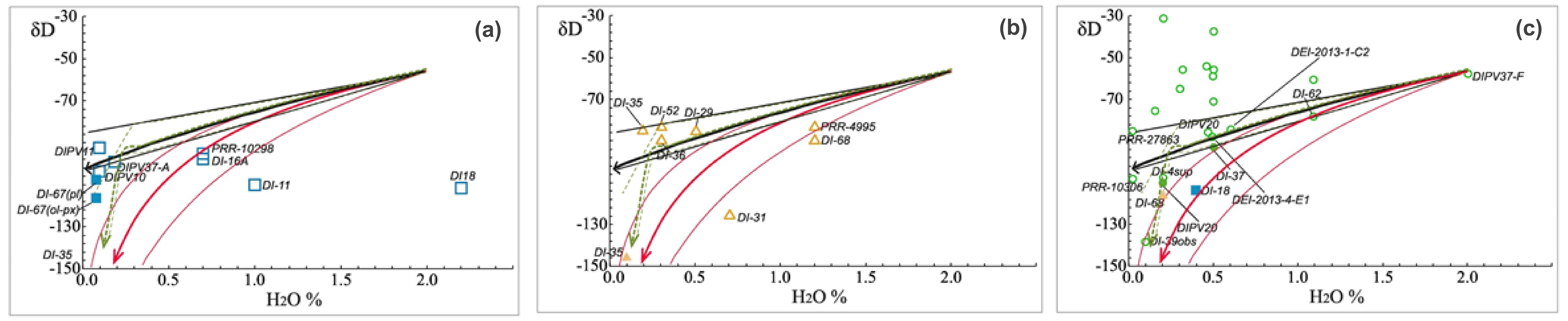


Plots of δD, δ[18]O and H_2O (%) as a function of their stratigraphic position (pre-, syn- and post-caldera). Hot-spring, fumarolic and glacier-melt waters data are from Kusakabe et al. (2009). In (c) samples are grouped according to their connection to the two main tectonic fault systems in the island, i.e. NE-SW (sample name in italics) vs. NW-SE (sample name in bold-italics). (Modified from Alvarez-Valero et al. 2020).

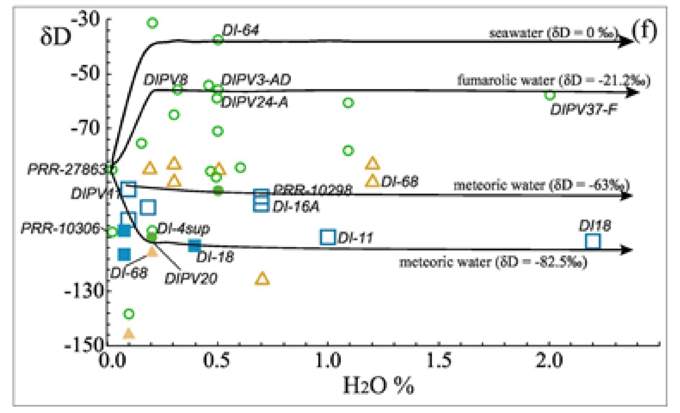
Degassing and rehydration processes

Our calculations for degassing in the Deception Island samples show that isotopic ratios and water contents of magmas are consistent with pre- to syn-eruptive degassing in either closed-, open- or mixed- systems of magmas with an initial δD value close to −55‰. While pyroclasts follow a closed-system degassing model, lavas degas in open-system conditions.

PRE-CALDERA | SYN-CALDERA | POST-CALDERA



Calculated degassing curves at closed- (red arrow), open- (black arrow) and mixed-system conditions (green dashed arrow), for the pre- (a), syn- (b) and post-caldera (c) samples. Water content variations from 1.5 to 2.5 wt% slightly change the curves slopes. Source: Alvarez-Valero et al (2020)



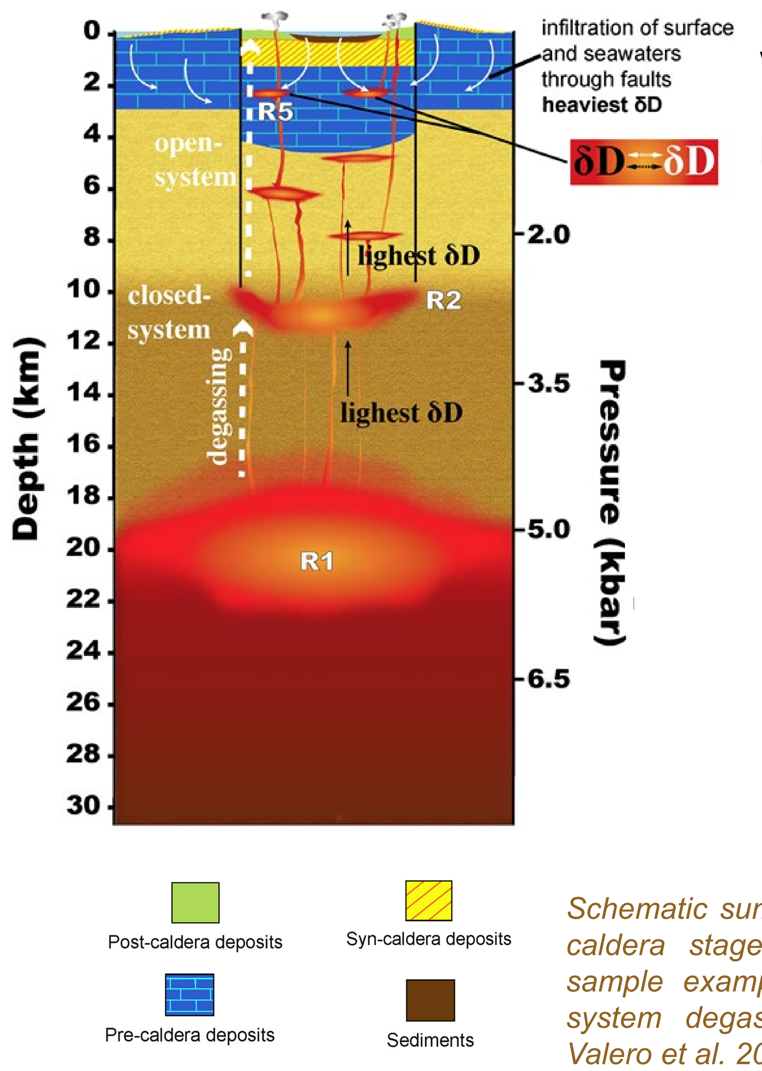
Examples of calculated post-rehydration curves for pre- and post-caldera samples (Modified from Alvarez-Valero et al. 2020).

The δD and δ[18]O isotopic values of the less degassed magmes point to no pre-eruptive interaction between magma and external water. This implies (i) a deep magma reservoir were infiltration of surficial water is limited, and (ii) the low porosity of the rock samples did not allow low-δ18O waters to circulate.

Deviations from the expected degassing trends are most probably related to post-emplacement rehydration (i.e. by surface weathering and/or hydrothermal alteration) of glass by seawater, fumarolic and meteoric waters of variable δD values.

Conclusions

(i) Fast ascent and quenching of most magmas, preserving pre-eruptive magmatic signal of water contents and isotopic ratios, with local post-emplacement modification by rehydration due to glass exposition to seawater, and by meteoric and fumarolic waters.



(ii) A plumbing system(s) variable with time and currently dominated by closed-system degassing leading to explosive eruptions

(iii) control on the interactions of ascending magmas with the surface waters producing hydrovolcanic activity throughout the two main fault systems

Our study demonstrates that geochemistry of stable isotopes is the complementary tool of the entire petrological information, to advance in the knowledge of magmas degassing and potential rehydration processes in an active hydrovolcanic system.

Schematic summary of the isotopic variation at the post-caldera stage of Deception Island highlighting some sample examples under closed- vs. open- vs. mixed-system degassing conditions (Modified from Alvarez-Valero et al. 2020).

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